Investment Analysis Report

Satellite Navigation

Mission Need Statement #50

January 9, 1998

Approved By: ______________________________
Director, Investment Analysis Staff
ASD-400

Concurrence: ______________________________
Associate Administrator for Regulation and Certification
AVR-1

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Investment Analysis Team

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SATNAV Executive Summary

The FAA's current policy is to transition from the existing ground-based navigation and landing system to a satellite-based navigation system (SATNAV). To effect this transition, the en route, terminal, and Category I phases of flight will be accomplished with the Global Positioning System (GPS) and the Wide Area Augmentation System (WAAS); the Category II/III phase of flight will be completed with Local Area Augmentation System (LAAS). LAAS will also take care of some Category I locations where WAAS does not provide sufficient coverage or where there is a high-availability requirement.

Scope

The scope of this analysis is the navigation and landing domains.[1] It specifically addresses most of the issues the FAA has considered in transitioning its navigation and landing infrastructure from a ground-based system to a satellite-based system. This report combines the WAAS and LAAS investment analysis into a single, integrated SATNAV investment analysis in preparation for an investment decision by the Joint Resources Council (JRC).

The Satellite Navigation Investment Analysis Report (IAR) documents the activities undertaken by the SATNAV Investment Analysis Team (IAT). These activities include development of the SATNAV Acquisition Program Baseline (APB) and the IAR. The team was formed at the request of the Associate Administrator for Research and Acquisitions (ARA-1), in partnership with the sponsoring organization (the Associate Administrator for Regulation and Certification, AVR-1), the Navigation Integrated Product Team (IPT), and the Investment Analysis and Operations Research Staff (ASD-400).

This analysis was conducted with participation from several organizations (AVR, AND, ATS, ARP, ASD, and AGC). The report's recommendation, which captures the results of the investment analysis, will be presented to the JRC as it prepares for an investment decision on this capability.

Background

In the 1980s, the Federal Aviation Administration (FAA) began considering how a satellite-based navigation system could eventually replace the ground-based system. On October 23, 1992, the Transportation Systems Acquisition Review Council approved Mission Need Statement #50, *Application of Satellite Navigation Capability for Civil Aviation.* In 1993, the Secretary of Transportation and the FAA Administrator reported that early utilization of GPS for civil aviation was a strategic objective of the Department of Transportation. On April 22nd, 1994, the FAA accelerated the implementation of satellite based navigation and approved an acquisition for the Wide Area Augmentation System.

An 18-month window was established for completing both the initial and final operational system due to the inherent risks associated with an accelerated program. In August 1995, the FAA awarded a contract to Wilcox Electric, Inc. In April, 1996, after concerns about Wilcox's performance, projected schedule slips, and potential cost increases, the FAA terminated this contract. In order to minimize the adverse effects of this termination, the FAA entered into an

[1] Although the communications and surveillance domains are equally important to the NAS, they were not considered in this analysis.

interim WAAS contract with Hughes Aircraft Co. to continue WAAS development. Negotiations for this contract were completed in October, 1996.

With respect to the LAAS program, in February, 1996, prior to the initiation of the new Acquisition Management System, a Key Decision Point (KDP - 2) investment decision was proposed. At that time, the FAA Acquisition Executive deferred the investment decision pending further analyses, but approved demonstration and validation activity for developing standards for airborne and ground LAAS equipment. The Precision Approach and Landing (PAL) IAT was formed in January 1997 to undertake the formal investment analyses requested at KDP-2. Its activities were transitioned to the SATNAV IAT when ARA-1 combined the JRC review of the WAAS and LAAS programs in November 1997.

Requested JRC Actions

The SATNAV IAT is requesting the following from the JRC:

- Approval of the Acquisition Program Baselines for WAAS and LAAS.
- Approval of the recommended approach for LAAS full scale development.
- Acknowledgment of ground based NAVAID decommissioning costs.
- Acknowledgment of SATNAV risks and mitigation strategies.

WAAS Development Approach

The WAAS acquisition will be accomplished in three incremental steps, each building upon the previous one. Phase 1 consists of an initial operating capability. Phase 2 and Phase 3 efforts add functionality to the system to meet all requirements of the WAAS System Specification.

Geosynchronous (GEO) satellite services for WAAS Phase 1 are being acquired through COMSAT as a leased service. The particular satellites that will be used for Phase 1 are the INMARSAT Pacific Ocean Region satellite and the INMARSAT Atlantic Ocean Region West satellite. These two satellites are in orbit today and will be used to deliver the WAAS signal-in-space over the service volume.

Phase 2 and Phase 3 WAAS program will be implemented with options for future Pre-Planned Product Improvements (P^3I). Implementation of P^3I options allows the FAA to tailor the acquisition based on improvements in technology and capabilities that may be possible with new generations of equipment or satellites. Additional satellites beyond the initial two INMARSATS will be needed to provide dual coverage over the entire service volume and to meet the performance requirements as stated in the WAAS specification for full operational capability. The current plan involves acquiring these additional satellites as a leased service.

The Phase 3 system will satisfy required navigation performance requirements and will be interoperable with the Japanese Multi-Functional Transport Satellite-based Augmentation System, the Canadian WAAS, and other international augmentation systems such as the European Geostationary Navigation Overlay Service.

With Hughes taking over the WAAS development, Phases 2 and 3 may be combined, making a two phased approach.

LAAS Development Approach

The IAT considered three approaches for LAAS full scale development (FSD). **Approach 1 - FAA Funded**: In this approach, the FAA assumes responsibility for the research and development of the LAAS ground station initial capability. The FAA develops and acquires four initial capabilities that are used for proof of concept, testing, and evaluation before nationwide implementation. **Approach 2 - FAA and Industry Funded**: In this approach, the FAA and industry enter into a partnership arrangement for sharing the LAAS full scale development costs. The financial contribution as well as development responsibility for each partner are determined by a mutual agreement. **Approach 3 - Industry Funded**: In this approach, industry funds the full scale development effort with no funding from the FAA.

The recommended approach is Approach 2 - to work with industry and the users in a joint effort to develop LAAS. The FSD phase, FY99-02, would be funded by industry and the FAA in partnership. The FAA would provide in-kind services to industry developer(s) of the LAAS technology for Category I precision approach development. In the Category III development phase some small amount of funds for development and certification plus in-kind services would be contributed by the FAA. During FSD, four (4) LAAS will be developed for test and evaluation. After FSD, the FAA will acquire 139 LAAS for a total of 143 LAAS. The LAAS APB has been costed to reflect this cost sharing approach. If industry does not fully participate in LAAS development as anticipated, the LAAS program could breach the proposed APB either in cost, schedule or both.

Major Assumptions, Constraints, and Conditions

- WAAS and LAAS will be certified as sole means of radionavigation aboard an aircraft. (No backup required.)
    - WAAS outages can be mitigated by operational procedures and surveillance systems.
    - If a separate non-satellite navigation system is required for back-up, that decision will have to be made on its own merits, separate from the WAAS APB.
- The current WAAS program does not require access to the full capabilities of a second frequency, but does require use of the carrier portion of the second signal.
    - The current WAAS design uses the C/A code and carrier signals of the L1 frequency and the carrier only of the L2 frequency.
    - Use of the L2 frequency has not been guaranteed for the long term. The FAA is anxious to reach agreement with the DoD on the 2nd civil frequency for the far term solution.
    - If DoD presents DOT with an option for full use of a second frequency, along with a cost, that decision will have to be made on its own merits, separate from the WAAS APB.
- Additional satellites beyond the initial two INMARSATs will be needed to provide dual coverage over the service volume and meet performance requirements.
    - Current plan is to acquire these additional satellites as a leased service.

- At the expiration of the current INMARSAT lease, FAA will execute a lease for similar INMARSAT satellite services at similar cost.
- GPS Selective Availability will be turned off by 2001.
- WAAS reference stations will also be sited in Canada and Mexico at no additional cost to the FAA.
- The life cycle begins when the first system is deployed and continues for 15 years beyond the deployment of the final system.
- 80 percent of air carriers will wait to equip with WAAS until they equip with LAAS.[2]
- VOR/DME, ILS, NDB, TACAN (and MLS) will be phased out beginning in 2005 and will be complete by 2010.
- WAAS will provide precision approaches with minima equivalent to Category I ILS. LAAS will provide CAT I service at a few high-availability airports which may have a higher availability requirement than WAAS can support.
- Major components of the LAAS (receivers, processors, psuedolites) will be replaced every six years. Other equipment will be replaced less frequently or not at all during the life cycle of the system.
- Technology refresh to replace major components of the WAAS will occur over a two-year period every five years, beginning in 2006-2007.
- One LAAS will be installed at each qualifying airport.

Economic Analysis

The SATNAV economic analysis is based on "most likely" input values, though the inputs for many of the cost categories have a range of values. Risk assessment is a technique that captures the uncertainties of the input variables.

Two different techniques were applied to produce the risk adjusted economic analysis. The first technique is qualitative in nature and reports the risk as "low," "medium," or "high." The second technique applies a Monte Carlo Simulation and Risk Analysis Model to quantify the risk of inputs. The outputs of the assessment, or the results, have a range of values, each value representing a particular confidence level. The high-confidence value for costs is 80/20, which indicates that there is an 80% chance the actual costs will not exceed the estimated costs. The high-confidence value for benefits is 20/80, which indicates that there is only a 20% chance the actual benefits will be less the estimated benefits.

The table below illustrates program costs for WAAS and LAAS. WAAS costs reflect the negotiated contract with maximum quantities (48 reference stations and eight master stations) based on the stated requirements defined by the sponsor, AVR-1, to achieve the safety-critical system. These costs include leasing two INMARSAT satellites and three micro satellites. Technical analyses by Mitre and Hughes indicate that two INMARSAT satellites and three additional WAAS micro-satellites will most likely meet coverage and availability requirements. The analysis also indicates that there is a small probability that two additional (four total) satellites

[2] WAAS Cost-Benefit Analysis and ATA input.

could meet requirements, if optimally placed. Sensitivity analysis indicates minimal gain in availability if four additional (six total) satellites are used. Based on this analysis, and on discussions between the WAAS Product Team, Hughes, the National Reconnaissance Office, FAA SETA, and the IPT, the IAT used this information as input to the satellite cost model.

Program Costs for WAAS and LAAS (Then-year $M)

WAAS	Prior	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-16	Total
Total	253.5	152.9	70.4	172.7	164.2	159.6	132.2	134.8	135.9	163.8	157.5	121.2	121.7	1009.0	3,049.2
LAAS	**Prior**	**FY 98**	**FY 99**	**FY 00**	**FY 01**	**FY 02**	**FY 03**	**FY 04**	**FY 05**	**FY 06**	**FY 07**	**FY 08**	**FY 09**	**FY 10-21**	**Total**
Total		9.2	10.5	8.0	11.0	11.1	86.2	92.7	101.4	102.7	18.4	20.3	30.1	375.6	877.1
NAVAID Decommissioning									**FY 05**	**FY 06**	**FY 07**	**FY 08**	**FY 09**	**FY 10-21**	**Total**
Total									59.3	60.9	62.4	73.9	75.9	320.6	653.0

LAAS costs assume an FAA/industry partnership for full scale development of four initial systems and FAA acquisition of 139 systems for a total of 143 LAAS. These figures also include costs for the Approach Lighting System with sequencing Flashing lights (ALSF-2) and runway visual range for airports that currently do not have Cat II/III capability and will qualify for this capability under the LAAS program.

NAVAID decommissioning costs are costs for decommissioning en route and approach NAVAIDS replaced by WAAS and LAAS.

Net Present Value and Benefit/Cost Ratio

The two economic measures that are generally referenced when making an investment decision are Net Present Value (NPV) and Benefit/Cost (B/C) Ratio. The following table summarizes the results of the SATNAV economic analysis:

Range of Estimates* at the 20/80% and 80/20% Confidence Levels ($M)

	WAAS		LAAS		SATNAV	
	Range	Most Likely	Range	Most Likely	Range	Most Likely
PV Costs	1,090 - 1,230	1,190	296 - 319	297	1,390 - 1,540	1,490
PV Benefits	3,600 - 4,650	3,810	819 - 995	958	4,460 - 5,440	4,770
NPV	2,400 - 3,400	2,620	505 - 685	662	3,000 - 4,000	3,280
B/C Ratio	3.0 - 4.0	3.2	2.6 - 3.4	3.2	3.0 - 3.7	3.2

*/ Above Baseline - Includes present value of NAVAID decommissioning

Affordability Assessment

The IAT briefed the LAAS and WAAS APBs to the SEOAT on December 5, 1997, and again the following week. At these meetings the SEOAT decided that the LAAS APB was affordable under the current agency budget baseline.

The SEOAT also decided that the WAAS APB was affordable, from an F&E perspective, in FY00 and the out years. It was affordable in FY99 at the $2.3B level of funding that the agency was requesting. Below that level of funding the SEOAT noted that agency priorities have not yet been determined. Regarding the WAAS O&M costs, the SEOAT noted the cost increases over previous briefings in the out year O&M costs, due to satellite leasing costs. They noted that the O&M costs had not yet been coordinated with the Operational Requirements Management Team. They also noted that the lease cost could go down if satellites are shared with other FAA and/or non-FAA users

Recommendations

- Approve Acquisition Program Baselines for WAAS and LAAS.
- Approve an FAA/Industry partnered approach for LAAS full scale development.

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1. Introduction

This report documents activities conducted by the Satellite Navigation (SATNAV) Investment Analysis Team (IAT) that led to the development of the Investment Analysis Report (IAR) and Acquisition Program Baselines (APBs). As specified in the Acquisition Management System (AMS) and the Investment Analysis Process Guidelines, the report summarizes the mission need, requirements, assumptions, and risks. The report also documents the economic assessment, and the results of the affordability assessment conducted by the System Engineering Operational Analysis Team (SEOAT). Finally, it summarizes the IAT's recommendation to the Federal Aviation Administration (FAA) Joint Resource Council (JRC) for providing a satellite navigation capability in the National Airspace System (NAS) and it identifies recommended steps.

The FAA's policy to transition from the current ground-based navigation and landing system to a satellite-based system has been stated in several FAA documents. These include the FAA Strategic Plan and the FAA's Plan for Transition to Global Positioning System (GPS)-Based Navigation and Landing Guidance, July 1996. According to this policy, the Wide Area Augmentation System (WAAS) will provide the NAS with satellite-based en route and terminal navigation, as well as a precision approach capability. The Local Area Augmentation System (LAAS) will complete the transition to satellite-based navigation by providing Category II/III precision approach and landing service. LAAS will also provide Category I service at a number of sites where WAAS does not provide coverage or cannot meet availability requirements.

1.1. Background

In the 1980s, the FAA began considering how a satellite-based navigation system could eventually replace the ground-based system. On October 23, 1992, the Transportation Systems Acquisition Review Council (TSARC) approved Mission Need Statement (MNS) # 50, *Application of Satellite Navigation Capability for Civil Aviation.* In 1993, the Secretary of Transportation and the FAA Administrator reported that early utilization of the Global Positioning System (GPS) for civil aviation was a strategic objective of the Department of Transportation. On April 22nd, 1994, the FAA accelerated the implementation of satellite based navigation and approved an acquisition for the Wide Area Augmentation System (WAAS).

An 18-month window was established for completing both the initial and final operational system due to the inherent risks associated with an accelerated program. In August 1995, the FAA awarded a contract to Wilcox Electric, Inc. In April, 1996 after concerns about Wilcox's performance, projected schedule slips, and potential cost increases, the FAA terminated this contract. In order to minimize the adverse effects of this termination, the FAA entered into an interim WAAS contract with Hughes Aircraft Co. to continue WAAS development. Negotiations for this contract were completed in October, 1996.

With respect to the LAAS program, in February, 1996, prior to the initiation of the new Acquisition Management System (AMS), a Key Decision Point (KDP - 2) investment decision was proposed. At that time, the FAA Acquisition Executive deferred the investment decision pending further analyses, but approved demonstration and validation activity for developing standards for airborne and ground LAAS equipment. The Precision Approach and Landing (PAL) IAT was formed in January 1997 to undertake the formal investment analyses requested at KDP-2. Its activities were transitioned to the SATNAV IAT when ARA-1 combined the JRC review of the WAAS and LAAS programs in November 1997.

Results of the PAL Investment Analysis were a data source for this report.

1.2. Requested JRC Actions

The SATNAV IAT is requesting the following from the JRC:

- Approval of the Acquisition Program Baselines for WAAS and LAAS.
- Approval of the recommended approach for LAAS full scale development.
- Approval of WAAS Phase II/III Program/Satellite Strategy
- Acknowledgment of ground based NAVAID decommissioning costs.
- Acknowledgment of SATNAV risks and mitigation strategies.

2. Mission Need, Benefits, and Requirements

2.1. Mission Need

MNS # 50, *Application of Satellite Navigation Capability for Civil Aviation*, describes the current navigation capability shortfalls and their corresponding effect on capacity, safety and supportability issues. The MNS also addresses the manner in which a differential GPS-based system can improve and extend the FAA's ability to provide En route, Terminal, CAT I/II/III approach and landing services. The MNS states the following deficiencies with respect to precision approach capabilities:

> "Some qualifying airports for which service has been requested do not have an approach aid capable of providing the appropriate level of service. Current systems cannot be sited due to terrain constraints, lack of real estate or, in many cases, financial reasons. There is a backlog of approximately 600 precision approaches due to cost and logistics. More runways would qualify for this capability with lower cost of service."

The Mission Need Statement and the sponsor's revalidation statement required for the Investment Decision JRC is included in the JRC briefing package.

The primary mission of SATNAV is to provide a satellite-based navigation capability for all phases of flight in the NAS from en route through precision approach. GPS, when augmented with WAAS and LAAS, will provide a satellite based three dimensional, primary means navigation capability suitable for civil and military aircraft equipped with a certified GPS/WAAS/LAAS receiver. SATNAV will integrate all phases of flight in the NAS from departure, en route, and arrival through precision approach.

The secondary mission of WAAS is time distribution, which is accomplished by providing users with a time offset between the WAAS Network Time (WNT) and Universal Coordinated Time (UTC). This time offset is determined by the United States Naval Observatory (USNO) and passed to the Wide-Area Master Stations (WMSs) through an interface between the WAAS and the USNO.

2.2. Benefits

SATNAV, over a period of time, is intended to replace existing en route navigation and approach aids such as Very High Frequency (VHF) Omni-directional Range (VOR)/Distance Measuring Equipment (DME), Instrument Landing System (ILS), and Loran-C. Decommissioning the aging NAVAIDS will save the FAA O&M because it will replace 2,937 ground-based systems with 48 WAAS Reference Stations, eight WAAS Master Stations and 143 LAAS. This O&M savings is one of the major drivers behind the FAA's decision to invest in WAAS and, in general, to transfer to satellite navigation.

SATNAV will operate continuously, unaffected by interruptions due to corrective and preventive maintenance. WAAS and LAAS will provide the potential for any runway suitable for instrument approaches to become a candidate for implementation of a precision approach capability. Airport approach/runway lighting will have to be installed where necessary.

Given these factors, pilots will have access to many more airports and runways than are currently equipped with ILSs. This will offer benefits in terms of improved schedule reliability, reduced flight cancellations, and fewer diversions. Also in high density terminal areas there will be additional runways that may be used in instrument conditions and secondary airports available to absorb the capacity demands, thereby reducing delays.

The availability of accurate vertical guidance can be exploited for pilots who have only the capability to perform non-precision approach. Current procedures will be augmented in accordance with WAAS and LAAS Minimum Operating Performance Standards (MOPS) to provide vertical guidance along a predetermined descent path to the minimum decision height. This will enhance safety by reducing cockpit crew workload and minimizing the possibility of controlled flight into terrain.

SATNAV will also provide the opportunity to optimize en route operations. En route airways will no longer be dependent on the placement of ground based navigational aids. The present airway system can be restructured to provide users with shorter routes and improved use of altitude and upper winds. By exploiting the inherent flexibility in routing, alternate/parallel routes can be used to meet changing traffic situations and to improve recovery time after the lifting of flow control restrictions such as those caused by severe weather conditions. By increasing system capacity in high density areas, system delays will be reduced.

Improved navigation accuracy provided by SATNAV will offer the opportunity to incrementally reduce separation standards. Potential reductions include non-radar separations in en route airspace as well as terminal separations due to reduced obstacle clearance requirements and protected airspace. Reduced separation standards directly translate into increased system capacity and reduced delays; however, SATNAV will not eliminate delays which result from the variables of severe weather conditions and wake turbulence which can exist in the terminal or airport traffic areas.

2.3. SATNAV Requirements

GPS alone does not satisfy all requirements for civil air navigation. To meet these requirements WAAS and LAAS improve the integrity, accuracy, availability, and continuity of GPS by using special equipment that constantly monitors the GPS and GEO (geosynchronous) Satellite Transponder (GST) broadcast signals. WAAS equipment determines integrity, corrections for GPS satellites and the ionosphere, uplink integrity, and correction data to GSTs. This broadcast data enables users to improve their position accuracy and determine when GPS satellites should not be used.

2.3.1. WAAS Requirements

The Operational Requirements Document, Wide Area Augmentation System (WAAS) Application of Satellite Navigation Capability for Civil Aviation outline the basic requirements for WAAS. Table 2-1, En route through Nonprecision Approach (ENR-NPA) Goals and Definitions, and Table 2-2, Precision Approach Goals and Definitions, provide WAAS contract requirements for the initial operational capability (IOC) and full operational capability (FOC). The final capability will provide sole means navigation to aviation users. Continental US (CONUS) refers to the contiguous forty-eight states.

Table 2-1. En route through Nonprecision Approach Goals and Definitions

Term	Definition	IOC (CY 99)	FOC (CY 01)
Availability	That portion of time when WAAS can be used for ENR-NPA operations.	99.9% of the time.	99.999% of the time.
Accuracy- ENR-NPA Accuracy 95% Horizontal	Degree of conformance between a 95% estimated horizontal position and its true value.	Within 100 meters, 95% of the time.	Within 100 meters, 95% of the time.
Accuracy- ENR-NPA Accuracy 99.999% Horizontal	Degree of conformance between a 99.999% estimated horizontal position and its true value.	Within 500 meters, 99.999% of the time.	Within 500 meters, 99.999% of the time.
Integrity Probability of Broadcasting Misleading Information	Probability that WAAS or GPS broadcast data is misleading/wrong and could cause a flight hazard/accident.	99.99999% probability that misleading data is not broadcast.	99.99999% probability that misleading data is not broadcast.
Integrity Time-to-Alarm	Period of time that starts when an alarm condition occurs and ends when the user is notified.	8 seconds.	8 seconds.
Continuity	Probability that an ENR-NPA flight operation can be completed once it has started.	99.999%	99.999999%.
Service Volume	Volume in which ENR-NPA service is provided (Also called area of coverage).	Approximately one-half of CONUS and one-third of other areas.	CONUS, Hawaii, Puerto Rico and oceans in between. Most of Alaska.

Table 2-2. Precision Approach Goals and Definitions

Term	Definition	IOC (CY 99)	FOC (CY 01)
Availability	That portion of time when WAAS can be used for precision approach operations.	95% of the time.	99.9% of the time.
Accuracy 95% Horizontal	Degree of conformance between an estimated horizontal position and its true value.	Within 7.6 meters, 95% of the time in the horizontal axis.	Within 7.6 meters, 95% of the time in the horizontal axis.
Accuracy 95% Vertical	Degree of conformance between an estimated vertical position and its true value.	Within 7.6 meters, 95% of the time in the vertical axis.	Within 7.6 meters, 95% of the time in the vertical axis.
Probability of Broadcasting Misleading Information	Probability that accuracy data that exceeds the Integrity Alarm Limit is not broadcast.	99.999996% probability that misleading data is not broadcast during a precision approach operation. (150 seconds)	99.999996% probability that misleading data is not broadcast during a precision approach operation. (150 seconds)
Integrity Time-to-Alarm	Period of time that starts when an alarm condition occurs and ends when the user is notified.	6.2 seconds.	5.2 seconds.
Continuity	Probability that a precision approach flight operation can be completed once it has started.	99.945% per approach (150 seconds)	99.945% per approach (150 seconds)
Service Volume	Volume in which precision approach service is provided (Also called area of coverage).	Approximately one-half of CONUS and one-third of other areas.	CONUS, Hawaii, Alaska, and Puerto Rico.

Coverage changes within the service volume as GPS satellites move. The service volume will be dynamic during IOC. Users will be notified via their onboard avionics, and by the notices to airmen (NOTAMS) when the service is inadequate to conduct operations.

As recommended by the Delaney Panel and others, AIR, AFS, ATR, and AND have already begun a re-assessment of WAAS requirements. The IAT feels that WAAS requirements should periodically be re-assessed, considering WAAS development costs, technical risks, and LAAS development and capabilities. For Example, the Delaney Panel said "We hope the FAA will not get hung up on trying to drive .999+ availability everywhere, all the time."

2.3.1.1. WAAS Satellites

The FAA already has leased communications transponder space on INMARSAT satellites. Additional satellites beyond these initial two will be needed to provide dual coverage over the entire service volume. The additional satellites are expected to take maximum advantage of existing technology to minimize cost and schedule. These geosynchronous satellites' payloads must satisfy the following requirements:

- The satellite will receive the ground station signal and downlink the signal on the GPS Link 1 (L1) frequency and a C-band downlink frequency.
- Data sent in GPS L1 frequency will be used for two purposes: a) sending WAAS messages; and b) providing a GPS-like ranging source.
- The end state WAAS coverage includes North America and the Atlantic and Pacific Ocean regions. Coverage may be satisfied by more than one satellite to satisfy WAAS availability (>0.99999) and continuity requirements.
- Initial service date for these geosynchronous satellites is 2001.
- The geosynchronous capability could be implemented by the addition of a payload(s) on an existing satellite(s), new satellites, or a combination of new and existing satellites.
- Design must support reliability and availability requirements and define a replenishment strategy which minimizes life-cycle costs.

2.3.1.2. Ground Uplink Subsystems (GUSs)

GUSs will be established in conjunction with the FAA and will perform command and control, WAAS message formatting and timing, transmission of the resulting signal to the satellite, and validation of the satellite downlink signal.

2.3.2. LAAS Requirements

LAAS shall provide all-weather approach, landing, and surface navigation capabilities. The LAAS ground and airborne equipment shall be capable of processing the GPS civil signal code and carrier information. The airborne equipment shall also be capable of processing ground data transmitted over the LAAS data broadcast. The LAAS equipment shall be capable of estimating system accuracy and generating integrity flags when the system should not to be used for navigation.

The display information presented to the pilot shall be no different than that of the ILS. The information presented to the air traffic controller describing system status shall be as close to existing ILS status information as feasible. The LAAS shall provide the following information to ATC:

- Status and configuration of LAAS components and equipment.
- Representation of the GPS/LAAS coverage.
- Representation of level of service being provided to the coverage area (precision approach (CAT I, II, III), and surface navigation.
- Status of GPS satellites.

All LAAS equipment shall be sited at a secure location preferably on airport property and will require no additional security. No cryptographic equipment will be required to process the GPS civil signal-in-space (SIS).

2.3.2.1. LAAS Critical System Characteristics (CSCs)

2.3.2.1.1. Multiple Runway Service

The LAAS shall be capable of providing precision approach capabilities simultaneously to multiple runways.

2.3.2.1.2. Advanced Flight Procedures

The LAAS shall be capable of supporting advanced approach and landing procedures, (e.g., parallel approaches and curved approaches).

2.3.2.1.3. LAAS Avionics Interoperability

- All LAAS avionics (whether CAT I, II, or IIIa/b certified) shall be able to operate using the LAAS SIS broadcast by all LAAS ground systems.
- LAAS CAT I equipped aircraft shall be able to operate at a CAT III ground facility commensurate with its intended function and level of service authorized.
- CAT III equipped aircraft shall be able to operate at a CAT I ground facility commensurate with its intended function and level of service authorized for that specific location and crew complement.

2.3.2.1.4. Compatibility with Existing Systems

- Since the LAAS will be implemented as a replacement for an existing precision approach system, it shall be able to operate concurrently with existing precision approach navigation systems on a non-interfering basis.
- The airborne equipment shall provide the capability to interface with existing flight management systems.
- The airborne equipment shall provide the capability to interface with the existing automatic landing flight deck annunciation philosophy.

2.3.2.1.5. Data Security

The LAAS shall provide required civil aviation services without the need for encryption.

2.4. DoD Interoperability/JPALS Issues

The WAAS program is in direct coordination with the Department of Defense (DoD) through the GPS Joint Project Office (JPO). The most significant issue facing the Department of Transportation (DOT)/FAA and DoD is selection of the second civil frequency for the GPS Block IIF satellites by March, 1998. FAA presented its position to the DOT Project Office for Satellite Navigation Executive Committee on November 17 and is awaiting the DoD selection of preferred frequencies.

FAA is coordinating with DoD the issue of intentional and unintentional interference, jamming and spoofing of the GPS/WAAS signals.

The FAA GPS Product Team participates in the DoD Joint Precision and Landing System (JPALS) Integrated Product Team (IPT) meetings, and reviews and comments on key documents pertaining to the acquisition of the JPALS, such as their Analysis of Alternatives and the Operational Requirements Document (ORD).

2.5. Programmatic Interdependencies

WAAS is an enabling technology that provides the capability for all users to fly direct from any location in the NAS to anywhere in the world. Although this can be accomplished by currently available avionics and flight management systems, the cost per aircraft is still quite high. The high cost associated with purchasing avionics means that universal equipage with this capability, needed for free flight, will not occur in the near to mid-term future. By contrast, the low cost WAAS receiver, which by its nature is area navigation (RNAV) capable, will help ensure equipage of all system users. In addition, WAAS ensures that a common navigation reference is used by all system users. By itself, WAAS will not permit "free flight"; however, it is a critical component of the equipment changes needed to transition to this new concept of operations.

2.5.1. Surveillance

WAAS and GPS can also be used for surveillance. An aircraft's position and velocity, as derived from GPS/WAAS, can be elicited by secondary surveillance radars equipped with selective interrogation, or through the passive reception of airborne broadcasts, i.e., Automatic Dependent Surveillance - Broadcast (ADS-B). The requirements have been developed assuming that independent means of communication and surveillance are provided.

2.5.2. NIMS

Both WAAS and LAAS will utilize the NAS Infrastructure Management System (NIMS). This is a nationally integrated system that uses remote monitoring of the performance and status of NAS systems, and provides a degree of remote maintenance and control of those systems.

3. WAAS Program

WAAS includes a series of master stations, precisely surveyed reference stations, geosynchronous satellites, and the communications infrastructure to connect them. Through its broadcast from geosynchronous satellites, WAAS will provide improved accuracy through differential corrections (i.e., ionosphere delay, ephemeris [satellite location], and satellite clock); improved integrity through integrity monitoring based on ground-based observations of the GPS and WAAS signals; and improved availability through additional ranging sources.

3.1. WAAS Development Schedule

The WAAS acquisition will be accomplished in three incremental steps. Phase 1 consists of an initial operating capability. Phase 2 and Phase 3 efforts add functionality to the system to meet all requirements of the WAAS System Specification. Phases 2 and 3 may be combined.

WAAS Phase 1, scheduled for August 1999, will provide ranging signals and a ground integrity broadcast service that will allow GPS, together with WAAS, to be used as a primary system for domestic en route navigation and nonprecision approaches. That is, WAAS-equipped aircraft can be instrument flight rules (IFR) certificated without having other navigation avionics aboard (e.g., VOR/DME or automatic direction finding-ADF). However, procedural or operational restrictions will affect the availability of nonprecision approaches, and flights will be restricted during specific time periods or will be subject to appropriate procedural restrictions.

WAAS Phase 1 precision approach minima will initially be somewhat higher than current Category I ILS minimums while both the FAA and aircraft operators gain additional experience in its use. Procedural or operational restrictions will affect approach availability. During Phase 1, alternate airports will need to be based on visual approach procedures or on NAVAIDS other than GPS or WAAS, such as ILS, VOR/DME, or Non-Directional Beacon (NDB). The initial WAAS precision approach coverage area will be limited based on the location of WAAS reference stations.

Phase 2 will provide, in the year 2000, incremental improvements in FAA's ability to model WAAS coverage and real-time availability. Additional WMS, GUS, and GSTs will be operational, increasing the service volume compared to Phase 1. An increased number of published precision and nonprecision approaches will also be available.

At the end of Phase 3, which is scheduled for November 2001, WAAS will achieve its FOC. Additional master and reference stations will become operational, and the hardware installed earlier in the program will be upgraded to the current standard. WAAS will then provide a level of availability sufficient to replace the existing VOR/DME and NDB facilities, plus most Category I ILS facilities.

The Phase 2 and Phase 3 WAAS program will be implemented with Pre-Planned Product Improvements (P^3I). Implementation of P^3I options allows the FAA to tailor the acquisition based on improvements in technology and capabilities that will be possible with new generations of equipment or satellites.

The Phase 3 system will satisfy required navigation performance (RNP) requirements and will be interoperable with the Japanese Multi-Functional Transport Satellite-based Augmentation

System (MSAS), the Canadian WAAS, and other international augmentation systems such as the European Geostationary Navigation Overlay Service (EGNOS).

WAAS funding also provides for the development of operational standards, certification, WAAS receiver development, and procedures for the use of WAAS throughout the NAS. These initiatives include GPS procedures for use by air traffic, to enable direct routes, terminal instrument procedure (TERPS) validation, generation of unique approach procedures, obstacle clearance requirements, aircraft separation standards, airport surveys, pilot and controller training, and revision of FAA regulations and documents to reflect satellite navigation use. The FAA also will establish a capability to monitor the NAS system wide performance, predict service volume coverage, and publish NOTAMS in order to advise users of current systems status.

3.2. WAAS Satellite Services

The FAA already has leased communications transponder space on INMARSAT satellites from COMSAT, the US signatory to INMARSAT. The particular satellites are the INMARSAT Pacific Ocean Region (POR) satellite and the INMARSAT Atlantic Ocean Region West (AOR-W) satellite. These two satellites are in orbit today and will be used to deliver the WAAS signal-in-space over the WAAS Phase 1 service volume.

Additional satellites beyond these initial two will be needed to provide dual coverage over the entire service volume and meet the performance requirements as stated in the WAAS specification for full operational capability. At the WAAS Major Acquisition Review (MAR) on October 2, 1997, the WAAS Product Team made initial recommendations on the best methods to obtain satellite services. The current plan is to acquire these additional satellites as a leased service.

3.3. WAAS Satellite Functional Capability Assessment

The WAAS Product Team presently is considering several satellite design options that include the capabilities to support a multipurpose “bent-pipe” communications transponder. These capabilities could be shared among various NAS Communications, Navigation, and Surveillance (CNS) programs to satisfy their requirements for reliable and cost-effective transmission connectivity between end points. The Telecommunications IPT also identified additional potential NAS functions that could further justify and defray the overall cost of acquiring a multipurpose CNS satellite system for the FAA. However, for the purpose of baselining the program and conducting these analyses, only WAAS functions have been assumed for geosynchronous satellites at this time.

3.4. WAAS Precision Approach Implementation

3.4.1. Coverage

WAAS precision approaches will initially be published based on a combination of requirements for approach at specific airports and availability as projected by the Service Volume Model, and in accordance with the Phase 1 WAAS service volume availability. The WAAS precision approach coverage volume gradually increases to further distances from a reference station as data is collected to substantiate ionospheric performance. The coverage area for WAAS will eventually be based upon the Availability Coverage Model (ACM). The ACM is a deliverable for Phase 2 of the WAAS acquisition program.

3.4.2. Publishing Approaches

Precision approaches will also be published regardless of whether there is single or dual WAAS geosynchronous satellite coverage. Approaches will also be published if the approach availability with a 24 satellite GPS constellation exceeds 95%.

3.4.3. Obstacle Clearance Criteria

To facilitate rapid development of WAAS procedure design criteria, the initial objective is to apply criteria similar to that specified in Order 8260.36a (Microwave Landing System-MLS and ILS). Sufficient data must be collected before the IOC to substantiate the use of this criteria. New criteria will be developed, after IOC, if WAAS performance indicates adjustments are appropriate.

4. LAAS Program

LAAS will augment GPS at 143 airports in the NAS to support Category II and Category III precision approach operations. LAAS will also provide Category I precision approaches at a few sites which are outside of WAAS coverage, and at a few high-activity airports which may have a higher availability requirement than WAAS can support. LAAS eventually will also support ground operations such as collision avoidance and airport surface navigation and surveillance. The initial deployment of LAAS is expected in 2003 and the final deployment in 2006. The LAAS capability does not require WAAS, and its implementation schedule is independent of the WAAS program.

A LAAS installation is anticipated to consist of a precisely surveyed ground station with multiple GPS receivers, a VHF data transmitter, and one or more pseudolites[3], where needed, to increase availability[4]. The LAAS ground station will calculate differential accuracy corrections based on the station's location and on measurements taken from each GPS satellite. It will then broadcast the corrections, together with an integrity message, to aircraft within a 20 to 30 nautical mile radius of the airport.

4.1. LAAS Full Scale Development (FSD) Strategy

The investment analysis team considered three approaches for LAAS full scale development (FSD). The major difference between each approach is the funding source. All three approaches would begin in 1999 and end at the end of 2002. It should be noted that when FSD is completed at the end of 2002, the FAA would then acquire 139 additional LAAS ground stations for NAS implementation. Starting in 2003, the Facilities and Engineering (F&E) and Operations and Maintenance (O&M) costs for all the LAAS ground stations would be funded by the FAA for all three FSD alternatives proposed below. Regulatory and certification responsibility remains with the FAA regardless of the approach taken.

4.1.1. Approach 1 - FAA Funded

In this approach, the FAA assumes responsibility for the research and development of the LAAS ground station prototype. The FAA develops and acquires four (4) initial systems that are used for proof of concept, testing, and evaluation before nationwide implementation.

4.1.2. Approach 2 - FAA and Industry Funded

In this approach, the FAA and industry enter into a partnership arrangement for sharing the LAAS full scale development costs. The FAA development costs would be less than the cost of Approach 1 but more than Approach 3. The financial contribution as well as development responsibility for each partner are determined by a mutual agreement. The industry component could include airlines, manufacturers, airport authorities, and industry associations. This approach is attractive to the FAA because it decreases the FAA's financial commitment during the FSD and involves the user from the very beginning. The disadvantages arise primarily from any legal complications from the partnership arrangement. For the user, this ensures that the system is

[3] Pseudolites are ground-based transmitters of GPS-like signals that are used for ranging.
[4] The number and placement of pseudolites will depend on the topology of each site.

developed despite FAA funding shortages. If the FAA decides to pursue this approach, its share of the financial commitment would depend on the terms of the agreement.

4.1.3. Approach 3 - Industry Funded

In this approach, industry funds the full scale development effort with no funding from the FAA. The only FAA financial commitment is to maintain appropriate staffing for the Product Team during these years. Current industry trends indicate that manufacturers are willing to fund the development effort because there is large international market waiting for Cat I LAAS.[5] The clear advantage to the FAA is that minimal government development costs would be required, an option that is very attractive in austere budget times. (The FAA would still be responsible for acquisition, implementation, and maintenance of the LAAS ground stations throughout the NAS.) The disadvantage is that market conditions fluctuate, and there is a risk that manufacturers may change their position and lose interest in this technology.

4.1.4. Recommended Approach

The recommended approach is Approach 2 - to work with industry and the users in a joint effort to develop LAAS. The FSD phase, and acquisition of four initial systems FY99-02, would be funded by industry and the FAA in partnership. The FAA would provide in-kind services to industry developer(s) of the LAAS technology for Category I precision approach development. In the Category III development phase some small amount of funds for development and certification plus in-kind services would be contributed by the FAA. The LAAS APB has been costed to reflect this cost sharing approach. If industry does not fully participate in LAAS development as anticipated, the LAAS program will breach the proposed APB either in cost, schedule or both.

4.2. LAAS Deployment Strategy

One-hundred-and-forty-three LAAS will be deployed over the years 2003-2006 at the following types of airports:

- CAT I airports
  - Includes 17 airports where WAAS coverage inadequate
  - Includes 14 airports that require greater availability than WAAS can provide
- New Qualifiers for CAT II or CAT III
- Replacements for existing CAT II/III precision approach facilities (Will replace recently procured ILS Mark 20 near the end of their useful life)

[5] Business and Commercial Aviation, November 1997, *SCAT I: Stepping Stone to LAAS.*

5. Assumptions, Constraints and Conditions

5.1. General Assumptions

- WAAS and LAAS will be certified as a sole (primary) means of air navigation and landing guidance system. All ground based navigation and Category I ILS landing systems will be decommissioned by the end of the year 2010.
  - WAAS outages can be mitigated by operational procedures and surveillance systems.
  - If a separate non-satellite navigation system is required for back-up, that decision will have to be made on its own merits, separate from the WAAS APB.
- 20 percent of air carriers will equip with WAAS in 2001; the remaining 80 percent will equip with WAAS when they can equip with LAAS.[6]
- VOR/DME, ILS, NDB, TACAN (and MLS) will be phased out (decommissioned) beginning in 2005 and will be complete by 2010. System disposal and site clean-up will continue until 2015.
- The life cycle begins when the first system is deployed and continues for 15 years beyond the deployment of the final system.
- WAAS and LAAS economic analysis results include NAVAID decommissioning costs but the WAAS and LAAS APBs do not.
- Benefit categories for SATNAV are:
  - FAA Savings - NAVAID O&M savings.
  - User Efficiency - avoidance of cancellations, diversions, and delay due to low ceiling/visibility at departure or destination airport.
  - User Avionics Savings - cost savings because SATNAV receivers for domestic use are less expensive than current receivers.
  - User Avionics Weight Savings - weight savings of being able to remove VOR and DME receivers on air carrier aircraft when they equip with WAAS/LAAS.
  - Surface Navigation Benefits - the ability to navigate on the airport surface in any weather condition.
  - En route Benefits
  - Safety Benefits

[6] WAAS Cost-Benefit Analysis and Air Transport Association input.

5. Assumptions, Constraints and Conditions

5.2. WAAS Assumptions

- The current WAAS program does not require access to the full capabilities of a second frequency, but does require use of the carrier portion of the second signal.
    - ♦ The current WAAS design uses the C/A code and carrier signals of the L1 frequency and the carrier only of the L2 frequency.
    - ♦ Use of the L2 frequency has not been guaranteed for the long term. The FAA is anxious to reach agreement with the DoD on the 2nd civil frequency for the far term solution.
    - ♦ If DoD presents DOT with an option for full use of a second frequency, along with a cost, that decision will have to be made on its own merits, separate from the WAAS APB.
- Additional satellites beyond the initial two INMARSATs will be needed to provide dual coverage over the service volume and meet performance requirements.
    - ♦ Current plan is to acquire these additional satellites as a leased service.
- At the expiration of the current INMARSAT lease, FAA will execute a lease for similar INMARSAT satellite services at similar cost.
- GPS Selective Availability will be turned off by 2001.
- WAAS reference stations (WRSs) will also be sited in Canada and Mexico at no additional cost to the FAA.
- WAAS will provide Precision Approach capability with minima equivalent to Category I ILS. In certain locations WAAS will not fully satisfy CAT I requirements (as a consequence of availability or coverage problems). LAAS will provide CAT I service at these locations.
- The FAA's Transition Plan would be implemented as planned, i.e., the schedule of decommissioning would be followed.
- Only aviation related benefits are considered even though there may be significant benefits to other modes of transportation and to non-aviation users.
- The DoD will have responsibility of funding and managing GPS space segment and continue to provide GPS service beyond the year 2016.
- The FAA maintains the WAAS.
- For economic and investment analysis, the WAAS service life is from 1997 through 2016.
- Technology refresh to replace major components of the WAAS will occur over a two-year period every five years, beginning in 2006-2007.
- Direct Route Structure benefit estimate is based on the New England Study which states that there could be 1 minute direct route saving for selected flights studied. The high benefit estimate is based on the assumption that all commercial IFR flights

in the nation would save one minute, while the low estimate is based on this savings being realized on only 30% of all flights.

5.3. LAAS Assumptions

- Major components of the LAAS (receivers, processors, psuedolites) will be replaced every six years. Other equipment will be replaced less frequently or not at all during the life cycle of the system.
- No funding is provided by the Flight 2000 program.
- The LAAS analysis includes lighting and Runway Visual Range (RVR) costs for runways that are “new qualifiers” for Cat II/III.
- One LAAS will be installed at each qualifying airport.
- For costing purposes, the CAT III LAAS configuration was assumed for all ground stations.
- Aircraft equipage for LAAS is assumed to occur gradually during the transition period between ILS decommission and LAAS implementation.

5.4. Avionics Development

Based on conversations and discussions at RTCA meetings the WAAS equipage rate will lag until the LAAS MOPS is completed. The MOPS are expected to be completed during the summer of 1998. Several receiver manufacturers have stated their intent to place a slot in their WAAS receiver for a LAAS receiver card. This can only be accomplished if the LAAS MOPS are completed on schedule.

6. Economic Analysis

The SATNAV economic analysis is based on "most likely" input values, though the inputs for many of the cost categories have a range of values. Risk assessment is a technique that captures the uncertainties of the input variables.

Two different techniques were applied to produce the risk adjusted economic analysis. The first technique is qualitative in nature and reports the risk as "low," "medium," or "high." The second technique applies a Monte Carlo Simulation and Risk Analysis Model to quantify the risk of inputs. The outputs of the assessment, or the results, have a range of values, each value representing a particular confidence level. The high-confidence value for costs is 80/20, which indicates that there is an 80% chance the actual costs will not exceed the estimated costs. The high-confidence value for benefits is 20/80, which indicates that there is an 80% chance the actual benefits will exceed the estimated benefits.

A risk assessment is performed on each line item to obtain a risk adjustment (80% confidence) for that item. An independent risk assessment is then performed on the total to avoid placing "risk on risk."

To make the transition from analysis to budget and formal baselines, individual cost elements were adjusted proportionally in that yearly totals reflect the 80% confidence level for RE&D, F&E, and O&M as appropriate.

6.1. WAAS Economic Analysis

6.1.1. Life-Cycle Costs

These represent the life-cycle costs for the acquisition, installation, operation and maintenance, and support as well as costs for user equipage.

6.1.1.1. FAA Life Cycle Costs

The cost estimates reflected in Table 6-1 depict cost by major categories. To minimize cost growth as a result of “requirements creep” the Product Team has adopted a policy of “Design to Cost.” As new, high priority requirements are identified, existing requirements of lower priority will have to be identified and evaluated as offsets if the new requirements are to be satisfied. Increasing requirements should not be allowed to cause erosion of cost risk margins, or the margin between the high confidence (80/20%) and the “most likely” cost estimates.

Table 6-1. WAAS LCC with NAVAID Decommissioning Costs (Then-year $M)

WAAS	Prior years	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07
Life-Cycle Costs	***406.4***	***170.4***	***172.7***	***164.2***	***159.6***	***132.2***	***134.8***	***135.9***	***163.8***	***157.5***
Total w/ Decom	406.4	170.4	172.7	164.2	159.6	132.2	134.8	195.2	224.7	219.9

WAAS	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	Total
Life-Cycle Costs	***121.2***	***121.7***	**124.0**	**161.6**	**165.3**	**133.9**	**136.8**	**140.4**	**147.0**	**3,049.2**
Total w/ Decom	195.1	197.6	313.3	168.7	172.5	141.3	144.4	140.4	147.0	3,600.2

6. Economic Analysis

The “Prime Contract-Wilcox” line item represents the sunk cost prior to the Wilcox termination. The “Prime Contract-Hughes” line item represents the negotiated cost for Hughes Aircraft Company to continue WAAS development. WAAS costs reflect the negotiated contract with maximum quantities (48 reference stations and eight master stations) based on the stated requirements defined by the sponsor, AVR-1, to achieve the safety-critical system.

The “Terrestrial Communications” line item reflects initial communication cost estimate and actual costs for the first year of Terrestrial Communication lease.

The “NAS Implementation” line item encompassed costs for the development of standards, certification, WAAS receiver development, and procedures for the practical application of WAAS throughout the NAS. This includes such requirements and projects as GPS procedures development for use by air traffic, TERPS validation, generation of unique approach procedures, obstacle clearance requirements, aircraft separation standards, airport surveys, support for training programs for civil pilots, and revision of FAA regulations and documents to reflect satellite navigation use. The FAA will also establish the capability to monitor the NAS system performance, predict service volume coverage, and publish NOTAMS.

The “Technical Engineering and Program Support” line item include the support contract costs to the Product Team. This support includes: System Engineering support for Architecture, Design, Integration, Reliability, Maintainability, Availability, Configuration Management, System Safety, Human Factors, Test/Evaluation, and Acceptance/Commissioning; Software Technical support to model and simulate the WAAS to validate conformance with the WAAS Specification requirements, monitor and control the cost, schedule, and technical performance of the prime contractor during execution of the contract, provide an Independent Verification and Validation (IV&V) capability to analyze and evaluate the contractor’s software development performance and execute the software certification process for the WAAS software in compliance with RTCA/DO-178B. Technical support also includes the development and operation of the management information system tool (SNAPIT) used to analysis and provide visibility for cost, schedule, technical performance, and risk management data on the WAAS program.

“Technology Refreshment” is defined as the life-cycle support strategy that stresses periodic replacement of Commercial off-the-shelf (COTS) system components (e.g., processors, displays, computer operating systems) within a larger system to assure continued supportability of the system through an indefinite service life. Inevitably, COTS components (especially hardware) will be a major and growing proportion of virtually every future FAA system. Given this reality, COTS technology refreshment (of both COTS hardware and commercially-available software) must be considered as the potential preferred support strategy/ maintenance concept for all future system acquisitions.

The “Satellite Communications” line is for WAAS GEO Satellite services to improve the integrity, accuracy, availability, and continuity of GPS because GPS alone does not satisfy all requirements for civil air navigation. The FAA already has leased communications transponder space on the INMARSAT POR satellite and the INMARSAT AOR-W satellite. Additional satellites beyond these initial two will be needed to provide dual coverage over the entire service volume and meet the performance requirements as stated in the WAAS specification for full operational capability. The current plan is to acquire these additional satellites as a leased service.

Technical analyses by Mitre and Hughes indicate that two INMARSAT satellites and three additional WAAS micro-satellites will most likely meet coverage and availability requirements. The analysis also indicates that there is a small probability that two additional (four total) satellites could meet requirements, if optimally placed. Sensitivity analysis indicates minimal gain in availability if four additional (six total) satellites are used. Based on this analysis, and on discussions between the WAAS Product Team, Hughes, the National Reconnaissance Office (NRO), FAA SETA, and the IPT, the IAT used this information as input to the satellite cost model.

The FAA is in the process of issuing a request for information to industry to further refine satellite leasing costs. In a leased service agreement, the risk associated with satellites achieving technical and performance capabilities is transferred to the contractor. Thus cost growth associated with achieving the required technical and performance capabilities is minimized.

NAVAID decommissioning costs have been included in the economic analysis to more accurately depict the total economic picture. NAVAID decommissioning costs are not included in the WAAS APB because a plan for disposal and environmental clean-up has not yet been fully coordinated within the Agency. NAVAID decommissioning should be decided on its own merits at a JRC Investment Decision.

6.1.1.2. User Life Cycle Cost

Life-cycle costs of equipping with avionics associated with WAAS were estimated to be less than costs of continuing with avionics associated with ground-based navigation aids; therefore, user avionics were treated as a benefit rather than a cost.

6.1.2. Benefits

6.1.2.1. FAA Benefits

WAAS, over a period of time, is intended to replace existing en route navigation and approach aids such as VOR/DME, ILS, and NDB. If 2,525 sites were decommissioned by the year 2010, the total economic benefit would be approximately $1.4 billion (constant 97).

6.1.2.2. User Benefits

WAAS provides a satellite-based navigation system to maintain required levels of safe operations in the NAS and allows replacement of VOR, DME, ADF, and ILS receivers with a single WAAS receiver (en route through Category I precision approach). Additionally, WAAS provides improved safety when operating in reduced weather conditions due to precision vertical guidance on approach. WAAS provides an IFR area navigation system, with global coverage, leading to:

- Greater runway availability
- Reduced separation
- More direct en route paths
- New precision approach services
- Reduced disruptions (delays, diversions, or cancellations).

6. Economic Analysis

Table 6-2 illustrates the benefits to the users of WAAS:

Table 6-2. WAAS User Benefits (Constant 97 $M)

Benefit Driver	Benefit Metric	Economic Benefit
Reduced number of flight disruptions	Over 200,000 flights per year not disrupted by weather by 2006	648
Reduced accidents	Over 1,000,000 more flights per year use precision approaches	1,367
Fewer avionics required		612
Reduced fuel usage due to lighter avionics		30
Reduced flight times	Average flight 1 minute shorter by 2006	4,886
Total User Economic Benefit		**8,123**

6.1.3. Net Present Value

Net Present Value (NPV) is the difference between the present value (PV) benefits and the PV costs. If the results are positive, then the benefits are greater than the costs, and a project is economically beneficial. Using the 20 percent to 80 percent confidence values for the difference between incremental costs and benefits, the NPV has a range of $2.4B to. $3.4B.

6.1.4. Benefit/Cost Ratio

The benefit/cost (B/C) ratio is the ratio of “to go” PV benefits divided by “to go” PV costs to determine the relative economic merit of the candidate solution. If the ratio is greater than one, then the benefits are greater than the costs, and the project is economically justifiable. Using the 20 percent to 80 percent confidence values for the incremental costs and benefits, the WAAS B/C ratio ranges between 3.0 and 4.0. This is consistent with previous WAAS economic analyses briefed to the JRC on July 10, 1997 and again on August 5, 1997, which found B/C ratios between 2.2 and 5.2. The latter range was based on the assumption that there are some variables (e.g., the value of passenger time and time savings through route restructuring) that could change or vary the final outcome, but still provide a favorable B/C ratio.

6.1.5. Current vs. Previous WAAS Cost Estimates

The WAAS life-cycle cost estimate has increased $637.8M over costs presented to the JRC in July, 1997, and $519.8M over costs presented in a WAAS MAR in October, 1997. Table 6-3 highlights where the cost differences occur.

The major differences from the data reported in the October MAR are due to the addition of $129M for technology refresh and $500M for Satellite Communications. The October MAR had captured technology refresh in the O&M budget, estimating it at $118M. By decision of ASD-400 management, technology refresh was transferred to the F&E budget. There was a $36M decrease in Terrestrial Communications and a $60M decrease in other FAA O&M costs resulting from a reevaluation of the high and low cost estimates for inputs to the cost model.

Table 6-3. Cost Comparison (Then Year $M)

WAAS F&E	JRC 7/97	MAR 10/97	SATNAV IAR 1/98

Prime Contract	558.5	558.5	558.5
NAS Implementation	155.2	155.2	155.2
Communications Satellite Terrestrial	50.3 9.5	50.3 9.5	31.3 9.5
Tech. Eng./ Program Support	118.9	118.9	122.7
Technology Refreshment			129.4
Total	**892.4**	**892.4**	**1,006.6**
WAAS O&M	**JRC 7/97**	**MAR 10/97**	**SATNAV IAR 1/98**
Communications Satellite Terrestrial	499.4 210.0	750.2 335.1	1,250.8 299.8
FAA O&M	809.6	551.7	491.9
Flight Inspection & Procedures	(336.8)	(115.9)	(120.3)
Logistics	(219.5)	(124.4)	(149.3)
Maintenance	(164.0)	(276.3)	(188.0)
Disposition		(3.9)	(3.8)
Staffing & Miscellaneous	(69.3)	(31.2)	(30.5)
Total O&M	**1,519.0**	**1,637.0**	**2,042.6**
WAAS TOTAL	**2,411.4**	**2,529.4**	**3,049.2**

6.2. LAAS Economic Analysis

6.2.1. Life Cycle Costs

6.2.1.1. FAA Life-Cycle Cost

The life cycle costs below include R&D, F&E, O&M and Airport Improvement Program (AIP) costs for the FAA's full scale development and deployment of 143 LAAS. R&D costs include research and development for full scale development and technology refresh. R&D efforts are currently underway with Ohio University and Stanford University.

F&E figures include costs for system development, deployment and installation, technology refresh and ILS decommissioning. These figures also include costs for the Approach Lighting System with sequencing Flashing lights (ALSF-2) and RVR for airports that currently do not have Cat II/III capability and will qualify for this capability under the LAAS program. Center Line Lighting (CLL) and Touch Down Zone Lighting (TDZL) costs are also included in the analysis because it has historically been the airports responsibility to purchase these two lighting systems, both of those systems are expected to be AIP funded. The LAAS APB has been developed considering a sharing of F&E costs for LAAS FSD. Table 6-4 shows total costs. Table 6-5 reflects FAA costs in a joint FAA/industry development effort.

Table 6-4. Life Cycle Costs (Then-Year $M)

Years	FY	FY	FY	FY	FY	FY	FY	FY	FY 06	FY	FY	FY	Total

Detailed Cost Data contained in "Official Use Only" version

	98	99	00	01	02	03	04	05		07	08	09-21	
Total	**30.1**	**31.9**	**41.9**	**45.1**	**40.5**	**140.5**	**148.4**	**158.5**	**161.2**	**44.9**	**47.5**	**564.2**	**1454.8**

Table 6-5. FAA/Industry Joint Venture - Costs (Then-Year $M)

Years	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09-21	Total
Total	**30.1**	**31.9**	**30.1**	**33.7**	**34.4**	**140.5**	**148.4**	**158.5**	**161.2**	**44.9**	**47.5**	**564.2**	**1425.5**

Some of these costs (such as AIP lights and ILS O&M) are not included in the LAAS APB because the LAAS program will not be responsible for these costs. O&M costs include operations and maintenance for LAAS, ALSF-2, and RVR. The O&M elements that are included are site, sector and regional level maintenance, leased telecommunications, utilities, land leases, recurring training, recurring flight inspection and other cost elements. Baseline ILS O&M costs were also included in this analysis and are shown as a separate line. These costs extend until 2010 at which point the ILSs will be decommissioned.

The main driver of the total cost in Table 6-3 is the cost for the 93 ALSF-2 systems for new Cat II/III qualifying runways. One ALSF-2 costs about $1.75 M to procure and install and approximately $37,500 to maintain per year. This amounts to about 35% of both the F&E and O&M costs. The costs that are specific to LAAS (R&D, system acquisition and deployment and tech refresh) amount to less than 40% of the total cost. It is important to note that most of the remaining costs will be incurred regardless of the Cat II/III system that is procured (e.g., ALSF-2, RVR, CLL, TDZL and ILS baseline O&M).

6.2.1.2. User Life Cycle Cost

User lifecycle costs captured here are the LAAS avionics costs. All costs were calculated using these assumptions:

- Current Cat III equipped aircraft would continue to be Cat III equipped in the future.
- All Cat II air carriers will become Cat III equipped by 2004.
- Life cycle of avionics is 15 years.
- Users that are currently equipped with ILS will replace their avionics up until the year before LAAS equipage begins.

User costs in Table 6-6 include costs for the avionics, installation, upgrades, spares, certification, re-certification and down time. Table 6-7 depicts the user life cycle cost for LAAS. The upgrades will occur via service bulletins and will include enhancements in annunciation, human factors, and refinements in operational characteristics. The costs in the tables are the total life cycle costs of deploying a Cat II/III capability with LAAS.

Table 6-6. LAAS Avionics Cost Methodology

Cost Category	CAT III Air Carriers	Cat II Regional	Cat II GA
Avionics System	$42,150	$11,200	$10,000
Upgrades	30% of system		
Installation	40% of system	40% of system	40% of system
Spares	15% of system	15% of system	
Certification	$50,000 * 130 types	$50,000 * 140 types	
Recertification	$5,000 * 160 types	$5,000 * 140 types	
Down Time	None, during normal maintenance	$2,200 * 3 days	
O&M	7% of total capital per year	7% of total capital per year	7% of total capital per year

Table 6-7. User Life Cycle Cost for LAAS

	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09-21	Costs
Air Carrier	0.0	0.0	0.0	0.0	0.0	0.0	46.7	44.0	40.8	37.2	34.8	102.0	305.5
Regional/Commuters	0.0	0.0	0.0	0.0	0.0	0.0	6.6	6.6	5.8	4.4	4.2	16.2	43.7
GA	0.0	0.0	0.0	0.0	0.0	0.0	5.3	4.9	2.3	2.2	4.0	8.9	27.7
O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	2.4	2.0	1.7	5.0	13.8
ILS Transition Costs	15.1	27.9	30.1	36.5	50.6	51.6	0.0	0.0	0.0	0.0	0.0	0.0	211.8
LAAS Total	15.1	27.9	30.1	36.5	50.6	51.6	58.5	58.2	51.2	45.8	44.7	132.2	602.4

6.2.2. Benefits

6.2.2.1. FAA Benefits

As shown in Table 6-8, the FAA will realize O&M savings because LAAS O&M will cost less than ILS O&M. LAAS O&M is less expensive for several reasons:

- One LAAS can replace several ILSs at an airport
- ILS consists of a localizer, glide slope and marker beacons where LAAS is a single system

Additional O&M savings will accrue because LAAS will enable decommissioning ILSs. There are O&M benefits in 2001 - 2003 because without LAAS, the life cycle of ILSs would have to be extended through a Service Life Extension Program (SLEP). The avoidance of SLEP costs are a benefit to LAAS. In 2004, there is a negative benefit (denoted by an asterisk) because both ILS and LAAS will be maintained. In 2010, all of the ILSs will be decommissioned and the positive benefits resume.

Table 6-8. LAAS FAA Benefits

	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11-21	Total
O&M Benefit	0.0	0.0	0.0	0.9	0.9	0.8	*	*	*	*	*	*	0.3	10.6	13.5

6.2.2.2. User Benefits

LAAS user benefits include reduced delays, weight savings, avionics cost savings and surface navigation benefits.

Delay benefits are economic savings based on reduction of airborne or ground disruptions. These benefits are realized when investment in a system results in opening an airport to traffic when weather would have otherwise closed it. In this analysis, these benefits are applicable to the airports/runways that are "new qualifiers" and receive a Cat II/III LAAS system where it only had a Cat I ILS system before. The Air Transport Association determined that the airlines could save between $69 - 138 M per year in the terminal area at their "top ten" airports[7].

When users equip with WAAS, they will be able to remove VOR, NDB, and DME receivers on their aircraft which will result in a weight/fuel savings. This analysis assumes that 80% of the air carriers will wait to equip with WAAS until LAAS receivers are available. Because of this assumption, it is proper that LAAS receives the weight savings benefits for these aircraft.

Even though the investment analysis team was not able to quantify surface navigation benefits for LAAS, it is believed that users will benefit from LAAS's surface navigation capabilities.

Table 6-9. LAAS User Benefits ($M)

	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11-21	Total
User Benefit	0.0	0.0	0.0	0.1	0.1	0.2	10.7	28.0	42.7	54.3	64.6	61.6	58.8	484.7	805.7

6.2.3. Net Present Value (NPV)

NPV is the difference between the PV of benefits minus the PV of costs. If the results are positive, then the benefits are greater than the costs, and a project is economically beneficial. Using the 80% confidence values for the incremental costs and 20% confidence value for the benefits, the Net Present Value ranges between $505M and $685M.

6.2.4. Benefit/cost Ratio

The benefit/cost ratio of "to-go" PV benefits divided by "to-go" PV cost to determine the relative economic merit of the candidate solution. If the ratio is greater than one, then the benefits are greater than the costs, and the project is economically justifiable. Using the 80% confidence values for the incremental costs and the benefits, the LAAS Benefit Cost Ratio ranges between 2.6 and 3.4. This range is based on the assumption that there are some variables that could change or vary the final outcome but still provide a favorable benefit to cost ratio.

6.3. SATNAV Economic Analysis

The economic analysis considered the following criteria: Life-Cycle Costs (FAA), Cycle Costs (Users), Benefits (FAA), Benefits (User), NPV, and B/C Ratio. All figures are expressed in then year dollars or 1997 present value dollars whichever is appropriate to the analysis. Risk assessment is a technique to analyze the economic analysis that captures the uncertainties of the input

[7] Because the investment analysis team could not get more detailed information on the assumptions used in the ATA study, these specific figures were not used in our benefit calculation. However, the study's results do verify the assertion that LAAS delay benefits will be substantial.

variables. The analysis was based on "most likely" input values, though the inputs for many of the cost categories had a range of values. The risk assessment, discussed in depth in Section 7, summarizes the low-confidence and high-confidence values of the different cost categories:

- Low-confidence value: The low-confidence value is 20/80 which indicates that there is an 80% chance the actual costs will exceed the estimated costs.
- High-confidence value: The high-confidence value is 80/20 which indicates that there is a 20% chance the actual costs will exceed the estimated costs.

Table 6-10 summarizes the results of the SATNAV economic analysis:

Table 6-10. Range of Estimates at the 20/80% and 80/20% Confidence Level ($M)

	WAAS*		**LAAS***		**SATNAV***	
	Range	Most Likely	Range	Most Likely	Range	Most Likely
PV Costs	1,090 - 1,230	1,190	296 - 319	297	1,390 - 1,540	1,490
PV Benefits	3,600 - 4,650	3,810	819 - 995	958	4,460 - 5,440	4,770
NPV	2,400 - 3,400	2,620	505 - 685	662	3,000 - 4,000	3,280
B/C Ratio	3.0 - 4.0	3.2	2.6 - 3.4	3.2	3.0 - 3.7	3.2

*/ Above Baseline - Includes present value of NAVAID decommissioning

7. Risk Assessments

Risk analysis and assessment is a technique to analyze the economic analysis that captures the uncertainties of the input variables. The WAAS and LAAS cost-benefit analysis was based on "most likely" input values, though the inputs for many of the cost and benefit categories had a range of values.

Two different techniques were applied to conduct the risk analysis and assessment. The first technique is qualitative in nature and reports the risk as "low," "medium," or "high" as it is rated by subject matter experts. Table 7-1 summarizes the risk details.

Table 7-1. Risk Factor Summary

WAAS	Risk Level	Mitigation	Revised Risk	Risk Drivers
Cost Estimate F&E O&M	 Medium - Low High	 Used 80/20 estimates	 Low Medium	 Contract "design-to-cost" Number of Satellites
Schedule	Medium			Phase 2 and 3 work packages not yet defined
Technical	Medium			Susceptibility to interference
Benefits Estimate	High	Used 80/20 estimates	Medium	Modeling & simulation approach for estimates of delay not validated. Sole means navigation not universally accepted

LAAS	Risk Level	Risk Drivers
Cost Estimate R&D F&E O&M	 Low Medium Medium	 Level of effort Pseudolites Maintenance concept (technical refresh)
Schedule	Medium-Low	Software development
Technical	Medium	Demonstrated flight tests of the multipath mitigating antenna. Successful flight tests of a pseudolite - demonstrating its feasibility. Software development still remains
Benefits Estimate	Medium	Volatility of Avoided Disruption Estimates

The second technique applies a Monte Carlo Simulation and Risk Analysis Model to quantify the risk of inputs. The outputs or the results had a range of values, each value representing a particular confidence level. The risk assessment summarizes the low-confidence and high-confidence values of the different cost and benefit categories as shown in Table 7-3, for WAAS and Table 7-5 for LAAS[8].

[8] Low-confidence value: For costs, the low-confidence value is 20/80. This indicates that there is an 80% chance the actual costs exceed the estimated costs. For benefits, the low-confidence value is 80/20. This indicates that there is an 80% chance that the actual benefits are lower than the estimated benefits.

High-confidence value: For costs, the high-confidence value is 80/20. This indicates that there is a 20% chance the actual costs exceed the estimated costs. For benefits, the high-confidence value is 20/80. This indicates that there is a 20% chance that the actual benefits are lower than the estimated benefits.

7. Risk Assessments

7.1. WAAS

The risk assessment of the WAAS program was conducted in the categories of technical, operational, schedule, cost, equipage, and benefit risks, reflecting the three phases of the contract. Phase 1 is currently underway and close to its completion date in early 1999. It contains minimum signal-in-space and operational capabilities. Its cost and operational performance risks are considered as negligible or non-existent. Therefore, risk assessment was not analyzed in Phase 1.

The Phase 2 adds several components and an extensive operational capability; however, there are no changes to signal-in-space requirements, except for an upgrade in en route through non-precision approach continuity. Phase 2 is scheduled to be fielded in mid 2000. The Phase 3 of WAAS adds several more components and contains the SIS requirements to make WAAS a primary means of navigation. Phase 3 is scheduled to be fielded in 2001. It is possible that Phases 2 and 3 may be combined under the Hughes contract.

Due to these factors, risk assessment was conducted in Phases 2 and 3 for F&E cost and schedule risk. The following details show the WAAS risk in the categories of technical/operational, schedule, cost, equipage, and benefits.

7.1.1. Technical/Operational

The technical/operational risk involves the probability and consequences of changing requirements, of programmatic interdependencies, or of a program's failure to achieve its intended technical and performance objectives of reliability, availability and accuracy, precision approach, security, backup, etc.

7.1.1.1. Reliability, Availability, Accuracy

At the request of the FAA, a WAAS Study Group, composed of members drawn from the 1995 Defense Science Board on GPS and headed by William P. Delaney, conducted a study of technical issues and challenges in WAAS. The Final Report of that board states:

> The FAA's specifications (reliability, availability, accuracy) are stringent, generally requiring three, four, or five "nines" (e.g., .99999!). There is no way to prove in advance that one can achieve such flawless operation; one relies on analyses and concatenated reliability calculations to support the design of the architecture. Our engineering judgment is that the WAAS can and will likely become the primary means of navigation and category-1 landing guidance even if it does not fully meet every last detail of these stringent requirements. One really needs to build the system, refine it in practice and let it mature to achieve these kinds of requirements.

7.1.1.2. SATNAV Backup

A recently released report from the President's Commission On Critical Infrastructure Protection casts doubt on the DOT policy of using the GPS as the sole source of navigation. The report states that vulnerabilities of the information and communications infrastructure affect every aspect of the transportation industry, the "most significant projected vulnerabilities are those associated with the modernization of the NAS and the plan to adopt the GPS as the sole basis for radionavigation in the US by 2010........ Although cost-efficient, this creates the potential for single-point failure." The report says that systems with air-ground communications and data links such as the ADS-B mode, the Air-ground Data Link (ADL) and the WAAS/LAAS are “susceptible to interference and signal jamming.”

The commission recommends that the Transportation Department:

- Fully evaluate actual and potential sources of interference to, and vulnerabilities of, GPS before a final decision is reached to eliminate all other radionavigation and aircraft landing guidance systems.
- Sponsor a risk assessment for GPS-based systems used by the civilian sector, projected through 2010.
- Base decisions regarding the proper federal navigation systems mix and the final architecture of the NAS on the results of that assessment.

The European Commission passed a resolution incorporating use of Loran-C as part of the European radionavigation mix. The Northwest European Loran-C System (NELS) consortium of six countries plans to provide differential corrections of GPS signals using Loran-C transmitters. They say Eurofix will provides a positioning and navigation system with an accuracy of two of five meters throughout Europe. Because Loran-C is a positioning and navigation system in its own right, it provides a backup in event of loss of GPS signals. The Loran transmitters on the ground will add the equivalent of 24 satellites to GPS because they are timed to the UTC standard. DOT Office of Transportation Policy officials state that Loran-C in the US is to be phased out by 2000.

7.1.1.3. Ionospheric Uncertainty During Solar Maximum (~CY 2000)

A key element of WAAS service is to provide ionospheric error correction to WAAS users. This is especially important during precision approach. The ionosphere generally changes slowly during periods of normal solar activity and current WAAS values are accurate enough to allow for a high availability of precision approach. The sun goes through an 11 year cycle and there are peak years when solar storms can disrupt the ionosphere. This makes the ionosphere corrections less accurate, potentially reducing the availability of precision approach. There is limited data available from the last solar maximum, leading to uncertainty associated with the measured periods of high solar activity.

The WAAS must overcome two key elements of the solar maximum phenomenon, channel fade and ionosphere delay. The current WAAS design uses the C/A (course/acquisition or “civilian”) code and carries signals of the L1 frequency and the carrier only of the L2 frequency. Use of the L2 frequency has not been guaranteed for the long term. The White House Commission on Aviation Safety and Security “called for the establishment of a second civil frequency as part of a broader program to maintain US leadership in aviation and satellite technology.” The DoD and DOT agreed to select a second civil frequency by March 1998, for use on the GPS Block IIF satellites. The FAA is anxious to reach agreement with the DoD on the second civil frequency for the far term solution. If the second civil frequency is the current L2, there will be an estimated one-time cost of about $50 million to change the Hughes contract to equip all WAAS reference stations and master stations with the capability to receive and process the new coded signal. If aircraft equip for dual frequency, ionospheric corrections can be computed independent of WAAS reference stations. In this case, there will be an offsetting cost reduction of about $167 million by reducing the number of WAAS reference stations. If the second civil frequency is not the current L2, then the costs to DOT for modifying 27 Block IIF satellites could reach $250 million. If it is decided to retrofit the first six Block IIF satellites already under contract with the new frequency, undetermined additional costs will be accrued. There is also discussion within DoD that some of the remaining 20 Block IIR satellites should be retrofitted, additional unestimated costs would accrue.

For the near term, the current two-frequency design may not be able to meet all the precision approach requirements during peak solar activity. WAAS has recently completed Critical Design Review using the L1 code and carrier and the L2 carrier design. This design is believed to mitigate all but the most extreme solar activity in certain polar and equatorial regions, and according to analysis by Mitre, Alaska, Hawaii, Puerto Rico, and areas of the West Coast. Channel fade, defined as the loss of lock-on signals from the satellites, is expected to affect the equatorial and polar regions and could have minor affect on parts of the WAAS service area. Additional studies and analyses are underway to provide a clearer picture of the technical options available.

7.1.1.4. Precision Approach

The WAAS architectural design is dominated by the precision approach requirements. The WAAS Study Group agreed with the FAA’s approach of considering the use of LAAS stations to meet precision approach requirements at locations difficult to service by WAAS precision approach. The group also encourages a continuing navigation system design process that provides for a smooth integration of WAAS and LAAS and continuously reviews the balance between the two systems in achieving the overall navigation solution.

Errors caused by ionospheric perturbations are the principal risk in achieving the precision approach accuracy requirements. Sufficient data on severe ionospheric disturbance periods does not exist, but such an ionosphere epoch is approaching. Evidence to date suggests we can correct the ionosphere quite well and our judgment is that the WAAS will be able to deal with ionospheric perturbations although it may take some time to evolve and tune the approach. In the meantime, the FAA should retain its plan to gradually reduce decision height minima as real world experience is accumulated..

7.1.1.5. Security

The WAAS Study Group investigated GPS security issues. They felt that GPS signals are unusually weak signals and unintentional interference from other electronic equipment is a concern. The report states that unintentional interference does not appear to be a prominent problem but they recommend continued vigilance in this area. The FAA has conducted a substantial effort to measure this interference and the results are very encouraging.

7.1.1.6. Jamming

Jamming can be done on all current FAA systems and is a primary concern of the FAA’s Spectrum Policy and Management Office. They are deeply involved in the process of ensuring the best possible protection to the GPS signal including being able to respond to individual acts of intentional or unintentional jamming. A Russian company named AVIACONVERSIA marketed and displayed a portable GPS and GLONASS jamming device at the Moscow Air show held August 19 to 24, 1997. Any NAVAID can be jammed including VOR's and ILS's. All military forces have a wide range of jamming capabilities in their electronic warfare arsenals which could jam any civil navigation aid. The fact that the Russians have such a jammer for GPS/GLONASS is not surprising. Any navigation jamming device is a concern to all aviation. It is illegal to jam aviation frequencies and internationally, spectrum protection from unlawful interference is protected by the Chicago convention. The FAA, with DoD, is working cooperatively to address both unintentional and intentional jamming of GPS to ensure the system is safe for civil use.

7.1.1.7. Sole Means Navigation

The NAS Architecture, version 3.0, states that retaining ground-based systems beyond 2010 to backup or complement the satellite-based systems is not expected to be necessary. The first defense against a localized loss of GPS service would be the continued service provided by air traffic control, surveillance, and collision warning and avoidance systems[9], vectoring affected aircraft to visual conditions or to a region unaffected by the loss of the GPS signal.

7.1.2. Cost/Schedule

The schedule risk involves the probability and consequences of failing to implement the system by the planned dates. A schedule slippage or delay in the system implementation will have a negative effect on both costs and benefits. The negative impacts of schedule risk are covered under cost and benefit risk estimates.

The overall assessment is that there is a minimum risk with the contract costs of the WAAS program. Phase 1 is nearing its completion and the remaining activities of Phase 1 do not have significant risk either in cost or schedule.

Compared to Phase 1, Phases 2 and 3 are assumed to have some risk, since work-package-level definitions are not yet determined. The current Phase 2/3 costs are based on estimates provided by the contractor. The risk assessment of Phases 2/3 also included an implicit adjustment to the uncertainty ranges of the cost components, reflecting the impact of the eight-month accelerated program implementation schedule. Furthermore, the Product Team's philosophy is “design-to-cost” that reduces the risk for the contract portion costs.

While the risk associated with the contract costs is low, the risk associated with the non-contract F&E categories of Phase 2/3 seems to be high. The Phase 2/3 categories include the areas of (1) Engineering and Programming support and (2) NAS Implementation.

Of all the risk categories, the highest uncertainty about the WAAS life cycle costs comes from satellite leasing costs, specifically the uncertainty about the number of GEOs required and the lease cost per year per satellite.

The following major categories, not included in the current risk assessment, are considered to have additional significant potential impact in increasing the WAAS costs:

- Funding availability for timely implementation (a one-year slippage in schedule results in additional program costs for maintaining the program and contract staff, costs to run the reference system, and loss of some benefit categories as opportunity costs).

[9] While these separation systems may evolve to make use of the GPS signals, they are being designed so they are not critically dependent upon GPS.

- New operational and performance requirements. (The Product Team's current budget estimate is based on no new requirements.)
- A back-up system for WAAS. (The potential need and cost of a back-up system should be analyzed.)
- Remote maintenance monitoring of WAAS. The WAAS Product Team will not be implementing RMMS (Remote Maintenance Monitoring System) during Phase 1 because a waiver to the RMMS requirement has been approved. There is an agreement with the NIMS Product Team on this issue. There are two approaches being considered for meeting the RMMS requirement in later phases: the current Remote Monitoring Subsystem (RMS), or follow-on RMMS, will get the data directly from the WAAS maintenance software via an interface still unspecified. The second option is a WAAS maintenance terminal will be located in each of the three Operations Control Centers where WAAS equipment would be monitored.

7.1.2.1. Hughes Phase 1 Contract Costs

The risk assessment of this category is based on the Product Team's Risk Management Plan that clearly defined the risk areas, including the process of risk identification and mitigation.

The various contract data requirements list reports, Monthly Schedule Status Reports, Risk Abatement Plans and Risk Management Status Reports documented the various risks and the risk mitigation efforts. Of the 23 risk items identified so far, 20 items were closed and only three items were active as of August 18, 1997. Even these three active items have no impact on the costs.

As of today, there were two Engineering Change Proposals (ECP) for Phase 1. The two ECPs had some cost and schedule impacts, but did not result in exceeding the overall Phase 1 budget cost or schedule. Two Engineering Change Orders (ECO) did not have any cost and schedule impacts.

Several software items that are part of the critical path of the project management had slipped past the planned schedules, but there is no slippage in the overall Phase 1 program schedule. This is because the contractor was ahead of schedule with some of the other critical activities.

Overall, Phase 1 had a $2.3 million cost overrun. The software alone had a $4.3 million cost overrun due to low productivity, while there were savings in material and management areas. The net cost overrun of $2.3 million was considered to be within the "limits" of the $11 million management reserve baselined in December 1996.

7.1.2.2. WAAS Phase 2 and 3 Contract Costs

The current WAAS Phase 2 and 3 costs were based on Product Team's inputs and contractor's estimates. Currently, the Product Team is planning to consolidate Phases 2 and 3 into one activity so as to bring about some cost savings due to synergy. Yet, there is a cost uncertainty about the estimates since the work-package-level definitions of Phase 2 and 3 activities are not yet determined.

7.1.2.3. Other F&E costs (Phase 2 and 3 Satellites)

The non-contract portion of the Phase 2/3 F&E costs has two major cost drivers: (1) NAS Implementation and (2) Technical Engineering/Program Support. The Product Team is confident that the costs for these two categories should go down by at least 10% due to synergy of consolidating Phases 2 and 3. In the worst case, the Product Team estimated that the costs of these two categories could go up by 40%:

Cost Category	10% decrease	40% increase (worst case)
NAS Implementation	$12 million	$49 million
Tech Engr/Program Support	5 million	21 million

7.1.2.4. Operations & Maintenance (O&M)

The satellite leasing costs constitute the largest O&M cost percentage and the most uncertain of all the O&M cost categories. The satellite lease costs are uncertain because of the uncertainty in the number of satellites required and in the lease costs per satellite.

In addition to the two satellites acquired in Phase 1, WAAS needs two or more satellites to meet performance requirements as stated in the WAAS specification for full operational capability. The exact number of additional satellites is discussed in Section 6.1.1.1.

The unit satellite lease cost per year are estimated to range from $12M to $25M depending on the type of dedicated service, priority requirement for FAA communications over the other shared satellite communications, and market conditions.

The risk summary (Table 7-3) depicts the low and high-confidence values of the total O&M costs reflecting the uncertainty in the input values of the satellites and other uncertain categories of the O&M costs.

7.1.3. Avionics Equipage

The avionics equipage risk involves the probability and consequences of the users (Air Carriers, Air Taxis, and General Aviation) failing to equip with the required avionics at the assumed equipage rates and schedules. The user benefit categories of efficiency, fuel savings, and others are directly related to WAAS avionics equipage.

The WAAS user benefits were estimated assuming “high-risk” (slow) equipage rates. Therefore, since a conservative equipage rate was used, there is a low risk that variance in equipage will adversely impact the benefits.

In the economic analysis, it was assumed that only CAT I equipped Air Carriers (20% of the Air Carrier population) would equip with WAAS avionics and the remaining (80% of the Air Carrier population) would wait for a combined WAAS/LAAS avionics. It was also assumed that only one-half of the General Aviation aircraft and 5% of the Executive/Business aircraft were estimated to equip with WAAS. Table 7-2 contains the equipage rates that were applied to the total population expected to equip with WAAS.

Table 7-2. WAAS Equipage Rates

FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08

Air Carrier	0.0	0.05	0.1	0.2	0.3	0.5	0.7	0.9	1.0	1.0
Air Taxi	0.1	0.2	0.3	0.4	0.6	0.8	0.9	1.0	1.0	1.0
General Aviation	0.05	0.1	0.2	0.3	0.5	0.7	0.8	0.9	1.0	1.0
Exec./ Business	0.1	0.2	0.3	0.4	0.6	0.8	0.9	1.0	1.0	1.0

Since conservative estimate of equipage rates were used, uncertainty ranges were not included in the quantitative risk assessment.

7.1.4. Benefits

The benefits risk assesses the likelihood that the candidate solution fails to achieve the level of benefits anticipated in its design.

The following sections show the risk analysis and assessment of the two major categories of benefits for WAAS, (1) FAA, and (2) Users, and the five subcategories of the user benefits: (a) Route Restructure; (b) Safety; (c) Efficiency; (d) Avionics; and (e) Fuel.

7.1.4.1. FAA O&M Savings

The risk associated with the FAA benefits, which is only O&M savings, is directly linked to the risk of decommissioning the current ground NAVAIDS. Until the ground NAVAIDS are de-commissioned, there are no O&M savings. If the decommissioning schedule slips, the FAA benefits are reduced. As a most likely case, the economic analysis assumed decommissioning to start from 2005. The risk analysis and assessment assumed a two-year slip in decommissioning of the ground NAVAIDS.

7.1.4.2. Route Restructure

The risk with the route restructure benefits is directly linked to the equipage rate, benefits attributable to current GPS, Flight Management System (FMS), and other similar technologies, and benefits attributable to Free Flight. The economic analysis assumed that the route restructure benefits begin from 2001 after WAAS Phase 3 is operational. Table 7-3 shows the low and high-confidence values of this category.

In lieu of a most likely route restructure benefits, the economic analysis estimated a low and a high estimate. The low estimate assumed that only 30% of the flights would realize one-minute flight-time saving per flight. The high estimate assumed that 100% of the flights would realize one-minute flight-time saving per flight. The risk analysis and assessment captured the uncertainty of this category by assuming a uniform distribution between the low and high estimates

Table 7-3. Risk (Quantitative) Summary

WAAS		Most Likely	Low-Confidence	High-Confidence
To Go Costs: (Current $M)	F&E Contract	410	410	420
	F&E Decommissioning	490	380	550
	F&E: Other	300	280	340
	O&M	1,330	1,170	1,520
	Total	2,530	2,320	2,830
To Go Costs: (PV $M)	F&E Contract	330	320	330
	F&E Decommissioning	170	130	190
	F&E: Other	210	170	210
	O&M	480	420	550
	Total	1,190	1,090	1,230
Benefits: (PV $M)	FAA	500	680	500
	Route Restructure	1,890	2,820	1,860
	Safety	590	650	560
	Efficiency	270	320	270
	Fuel / Avionics	560	560	350
	Total Benefits	**3,810**	**4,650**	**3,600**
	Net Present Value	**2,620**	**3,400**	**2,400**
	B/C Ratio	**3.2**	**4.0**	**3.0**

7.1.4.3. Safety

The risk with the safety benefits is directly linked to system performance and availability. The economic analysis did not include GA and Military to estimate safety benefits due to an earlier problem in the GA accident data base that mistakenly included an air carrier accident which happened outside the United States. But this exclusion of GA and Military did not have any significant impact in the benefit-to-cost ratio estimated earlier by including the above mentioned air carrier accident.

Other than this, there are no substantial, WAAS-related uncertainties about safety benefits and the category is not part of quantitative risk assessment.

7.1.4.4. Efficiency, Avionics, and Fuel

The risk with the benefit categories of efficiency, avionics, and fuel are directly linked to the avionics equipage risk discussed under Section 7.1.3. Since conservative avionics equipage rates were used, these three categories of benefits are not part of quantitative risk assessment.

7.2. LAAS

The LAAS risk assessment was conducted in the categories of technical, operational, schedule, cost, and benefit risks.

7.2.1. Technical/Operational

Technical risk exists for LAAS due to multipath interference, radio frequency interference (RFI), and integration of LAAS avionics with the FMS and autopilot.

Multipath interference is considered the largest performance risk affecting the accuracy of the navigation signal. To mitigate this risk, several flight tests have been performed to investigate multipath using a novel antenna design. While these antennae actually performed better than anticipated (pseudorange errors less than 0.2 meters), some risk still remains.

RFI is a matter of concern in any radio navigation system. Like all systems which depend on radio transmission, both LAAS and ILS are susceptible to both accidental and intentional interference. Protecting these safety-critical systems from RFI is vital to ensure safety of operation in the terminal area. In the GPS/LAAS configuration, a potential exists for RFI to the GPS receiver and to the data link. GPS operates at 1575.42 MHz ±10 MHz, and the data link uses a VHF frequency band of 112 - 118 MHz to transmit corrections to users. The GPS signal is vulnerable to interference because of the very low level of signal power received from the satellites. Unintentional or accidental interference can be dealt with through effective methods of quickly detecting and isolating the source of any potential interference.

Studies have been completed by RTCA Special Committee 159 to identify all potential emitters of signals that could interfere with GPS and to determine means of mitigating that potential interference (RTCA/DO-235, Assessment of Radio Frequency Interference Relevant to the Global Navigation Satellite System). While the GPS signal can be easily interfered with, it is very difficult to spoof the signal. The threat of spoofing the satellite signals is considered very unlikely due to the need for significant technical, logistics, and financial resources. The VHF radio navigation band has been used extensively and is essentially free of interference, and the risk to this spectrum is considered low. Overall, the potential risk of interference to the GPS/LAAS configuration is considered a low risk.

Although several tests have demonstrated LAAS's ability to provide improved performance compared to ILS, the system has yet to be fielded and tested in an operational environment. The SCAT-I experience and the ILS look-alike design of the LAAS will help reduce its performance risk.

7.2.2. Cost/Schedule

The cost estimate done for the analysis included costs for the LAAS ground station, approach lights, RVR, LAAS O&M, ILS O&M, ILS decommissioning, and other costs. The costs for the LAAS ground station were estimated using information gathered from the suppliers of the SCAT-I system and suppliers of similar components. Even though the team feels that the ground system cost estimates are very good, the system has not been developed yet, so there is some risk inherent in the estimate. However, one of the other main drivers in the costs (other than the LAAS system costs) is the cost of the approach lighting systems. These lighting systems are currently under contract so the cost risk for these is very low.

Another risk in the cost estimate is the risk of doing an FAA-industry partnership. There is a risk that industry will not participate to the extent that the team has planned. If that occurs, the FAA will have to spend an extra $30M from 2000-2002. The team does not think that this is a high risk because industry has already shown interest in participating in a partnership to develop LAAS. Therefore, using the risk factors stated above, the team determined that there was a medium risk in the cost estimate.

LAAS is a new technology whose critical performance parameters have been validated in several flight tests. The schedules for completion of the ground subsystem specifications and airborne subsystem minimum system performance standard are on track. There is ample time to develop safety critical software and prototypes before the first LAAS is declared operational. The operational implementation activities (such as procedure development, runway end, and airport surveys and certification of approaches for a total of 143 airports) can be easily accomplished within a four-year period. Therefore, the team considers LAAS as having low schedule risk.

The IAT has determined that there is support in the industry for sharing LAAS development costs. If, however, industry does not fully participate in LAAS development as anticipated, the LAAS program could breach the proposed APB either in cost, schedule or both.

7.2.3. Avionics Equipage

Equipage risk is the probability and consequences of users failing to equip with avionics at the assumed equipage rates and schedules. Equipage risk is due to resistance of the user community to change avionics and/or nonavailability of avionics. LAAS involves new avionics with substantial capital investment, with the risk of some resistance from the user community, particularly general aviation. This risk is reduced because the air carriers have been proponents of LAAS. This increases the probability of early and quick equipage by the air carriers (who account for the majority of the benefits).

It should be noted that any program delay will increase the risk of equipage delay, in particular, a LAAS delay may lead to the international community choosing to equip with other types of systems not compatible with LAAS.

Table 7-4. LAAS Avionics Equipage

Rapid LAAS	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12
LAAS ground systems	2	2	34	35	35	35						
LAAS air carrier equipage				20%	40%	60%	80%	100%	100%	100%	100%	100%
LAAS air taxi/regional equipage				20%	40%	60%	80%	100%	100%	100%	100%	100%
LAAS GA equipage				3%	10%	17%	24%	31%	34%	34%	34%	34%

7.2.4. Benefits

The benefits risk is the likelihood that the benefits estimate fails to fall within its proposed uncertainty bound.

7.2.4.1. FAA O&M Savings

Risks are the same as discussed in subsection 7.1.4.1.

7.2.4.2. Avoided Disruptions

The majority of benefits for LAAS are delay benefits due to avoided disruptions. These benefits are calculated using APO's establishment criteria for determining new qualifying runways for Cat II/III. Because benefits are calculated using established methodology and current airport data, the benefits estimate risk is minimized. However, a major benefits driver in both delay benefits and avionics savings is user equipage. With LAAS, the equipage rate is assumed; therefore, there is a high risk that the benefits may go down.

Table 7-5. Risk (Quantitative) Summary

LAAS	Most Likely	Low-Confidence	High-Confidence

7. Risk Assessments

Costs: (Then-Year $M)	R&D F&E❶ O&M AIP **Total LCC**	52 552 562 111 1277		
Costs: (PV❷ $M)	F&E: Total O&M **Total LCC**	297 ❸ 297	296 - 296	319 - 319
Bene-fits: (PV $M)	FAA User	16 942	16 979	13 806
Net Present Value		662	685	505
B/C Ratio		3.2	3.4	2.6

❶ Includes ILS Decommissioning ; ❷ Incremental costs; ❸ Incremental O&M Costs are a Net Benefit

8. Affordability Assessment

As part of any investment analysis, the IAT is required to obtain an affordability assessment of its recommended alternative(s) from the SEOAT, which is a corporate group that is charged with preparing recommendations on tradeoffs between F&E programs for review and approval by the JRC. While the SEOAT will focus its attention on F&E programs and dollars, it makes these decisions on a life cycle basis and considers O&M and R&D costs as well.

The IAT briefed the LAAS and WAAS APBs to the SEOAT on December 5, 1997, and again the following week. At these meetings the SEOAT decided that the LAAS APB was affordable under the current agency budget baseline.

The SEOAT also decided that the WAAS APB was affordable, from an F&E perspective, in FY00 and the out years. It was affordable in FY99 at the $2.3B level of funding that the agency was requesting. Below that level of funding the SEOAT noted that agency priorities have not yet been determined. Regarding the WAAS O&M costs, the SEOAT noted the cost increases over previous briefings in the out year O&M costs, due to satellite leasing costs. They noted that the O&M costs had not yet been coordinated with the Operational Requirements Management Team (ORMT). They also noted that the lease cost could go down if satellites are shared with other FAA and/or non-FAA users.

9. Recommendations

- Approval of the Acquisition Program Baselines for WAAS and LAAS.
- Approval of the recommended approach for LAAS full scale development.
- Approval of WAAS Phase II/III Program/Satellite Strategy
- Acknowledgment of ground based NAVAID decommissioning costs.
- Acknowledgment of SATNAV risks and mitigation strategies.

10. Next Steps

As indicated above, there are significant risk areas and areas of uncertainty in the estimates we have prepared. To increase our confidence in the estimates and to help the FAA better manage risks we recommend the following steps be taken as soon as possible:

- Assess the impact to the FAA of non-DoD Agencies sharing in GPS satellite replenishment costs.
- Perform detailed analyses on the benefits of direct routing to NAS users.
- Complete expanded analyses, using the results of the planned RFI, on the planned and next-generation satellite requirements.
- Conduct an analysis of backup for GPS/WAAS/LAAS. This should begin with the preparation of a mission analysis and mission need statements.
- Track the APB “Watch Items” and the risk mitigation efforts.
- Conduct, preferably by a national panel of scientific and technical experts, an independent assessment of interference risk.
- The Airports Line of Business in the FAA also needs to plan for additional SATNAV services, since they expect increased local and regional demand for WAAS/LAAS.
- The FAA-Industry partnership with the LAAS FSD needs to be aggressively pursued and tracked to ensure it works the way we envisioned it.

It is important that responsibility for these next steps be assigned and milestones be established.

Glossary

Term/ Acronym	Definition	Defined on Page
ACM	Availability Coverage Model	11
ADF	automatic direction finding	9
ADL	Air-ground Data Link	31
ADS-B	Automatic Dependent Surveillance - Broadcast	8
AIP	Airport Improvement Program	23
ALSF	Approach Lighting System with sequencing Flashing lights	23
AMS	Acquisition Management System	1
AOR-W	Atlantic Ocean Region West	10
APB	Acquisition Program Baseline	1
B/C ratio	Benefit/cost ratio	22
CLL	Center Line Lighting	23
CNS	Communications, Navigation, and Surveillance	10
CONUS	Continental US	4
COTS	commercial-off-the-shelf	20
CSC	Critical System Characteristic	7
C/A	course/acquisition	31
DME	Distance Measuring Equipment	3
DoD	Department of Defense	8
DOT	Department of Transportation	8
ECO	Engineering Change Orders	34
ECP	Engineering Change Proposals	34
EGNOS	European Geostationary Navigation Overlay Service	10
ENR-NPA	Enroute through Nonprecision Approach	4
FAA	Federal Aviation Administration	1
FMS	Flight Management System	36
FOC	full operational capability	4
FSD	Full Scale Development	13
F&E	Facilities and Engineering	13
GEO	geosynchronous (satellite)	4
GPS	Global Positioning System	1
GST	GEO Satellite Transponder	4

Term/ Acronym	Glossary Definition	Defined on Page
GUS	ground uplink subsystem	6
IAR	Investment Analysis Report	1
IAT	Investment Analysis Team	1
IFR	instrument flight rules	9
ILS	Instrument Landing System	3
IOC	Initial Operational Capability	4
IPT	Integrated Product Team	8
IV&V	independent verification and validation	20
JPALS	Joint Precision and Landing System	8
JPO	Joint Project Office	8
JRC	Joint Resource Council	1
KDP	Key Decision Point	1
LAAS	Local Area Augmentation System	1
L1	GPS Link 1	6
MAR	Major Acquisition Review	10
MHz	Megahertz	37
MLS	Microwave Landing System	11
MNS	Mission Need Statement	1
MOPS	Minimum Operating Performance Standards	4
MSAS	Multi-Functional Transport Satellite-based Augmentation System	10
NAS	National Airspace System	1
NDB	Non-Directional Beacon	9
NELS	Northwest European Loran-C System	31
NIMS	NAS Infrastructure Management System	8
NOTAMS	notices to airmen	6
NPA	non-precision approach	4
NPV	Net Present Value	22
NRO	National Reconnaissance Office	21
ORD	Operational Requirements Document	8
ORMT	Operational Requirements Management Team	41
O&M	Operations and Maintenance	13

Glossary

Term/ Acronym	Definition	Defined on Page
PAL	Precision Approach and Landing	2
POR	Pacific Ocean Region	10
PV	Present value	22
P^3I	Pre-Planned Product Improvements	9
RFI	Radio frequency interference	37
RMMS	Remote Maintenance Monitoring System	34
RMS	Remote Monitoring Subsystem	34
RNAV	area navigation	8
RNP	required navigation performance	9
RVR	Runway Visual Range	17
SATNAV	Satellite Navigation	1
SEOAT	System Engineering Operational Analysis Team	1
SLEP	Service Life Extension Program	25
SIS	Signal-in-space	7
SNAPIT	management information system test	20
TDZL	Touch Down Zone Lighting	23
TERPS	terminal instrument procedure	10
TSARC	Transportation Systems Acquisition Review Council	1
USNO	United States Naval Observatory	3
UTC	Universal Coordinated Time	3
VHF	Very high frequency	3
VOR	VHF Omni-directional range	3
WNT	WAAS Network Time	3
WAAS	Wide Area Augmentation System	1
WMS	Wide Area Master Station	3
WRS	WAAS reference station	16

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